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PROCEEDINGS

USMC Corrosion Reduction Program: Vehicle Corrosion Surveys at Camp Lejeune, Camp Pendleton, and Twentynine Palms Marine Corps Bases.

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INTRODUCTION

The United States Marine Corps (USMC) has recently identified corrosion of vehicles as a major problem area. Higher life cycle costs of equipment, reduced operational availability, and excessive manpower requirements to maintain operability are some of the problems associated with corrosion. Current corrosion control methods have been identified as deficient, either in effectiveness or ability to be implemented. The Amphibious Warfare Technology Directorate (AWT) of the Marine Corps Systems Command (MARCORSYSCOM) tasked the Naval Surface Warfare Center (NSWC) Marine Corrosion Branch to conduct research and development of new materials, procedures and design improvements which will reduce corrosion of USMC vehicles.

BACKGROUND

As an amphibious force, the United States Marine Corps is required to transport most of its equipment by ship and deliver it over-the-beach to shore. To permit rapid response in fulfillment of its mission, Marine Corps bases and equipment stockpiles are situated close to ocean ports. Forward-deployed equipment is primarily stowed in prepositioned ships. Not surprisingly, the primary operating environment of Marine Corps equipment is a marine environment, including seawater immersion during amphibious operations, splash and salt-spray during ocean transport and on the beach, as well as salt-laden air. This is a most agressive corrosion environment, and requires higher initial investment in equipment specifically designed to resist salt water corrosion and higher maintenance to achieve required vehicle lifetimes, ref 1-4.

Other than amphibious assault vehicles, most Marine Corps equipment is purchased by the US Army, whose inland mission removes

most of their equipment from exposure to the ocean environment. Neither Army bases nor training areas are normally located near saltwater areas, and as a result, no driving impetus exists in the Army procurement system to absorb initial higher costs associated with corrosion resistance to the marine environment. Marine Corps vehicles can be expected to have higher corrosion failures and associated maintenance burdens than Army (or Air Force) equipment.

For the most part, high initial procurement costs for more corrosion resistant equipment and vehicles eliminates the option of buying new materielle for all armed services that are suffiently corrosion resistant to provide adequate maintenance-free service for the Marine Corps. However in some cases, upgrading to improved standards will provide cost savings for all. For instance, it may be possible to upgrade some non-structural parts to non-metallic materials that are inherently corrosion-free and cheap. Some design aspects (such as drain holes in frames) are prudent for any service vehicle.

For those vehicles and equipment procured specifically by and for the Marine Corps only, it makes very good sense to include corrosion resistant design in the specifications. Improved availability for service and reduction in maintenance man-hours should provide ample cost-justification for some moderately expensive improvements during procurement, while some design aspects which impart improved corrosion performance are essentially free when included in the initial design.

Although corrosion control maintenance actions are currently required at each of the different maintenance echelons for USMC vehicles, little data has been summarized on the extent of use and resulting effectiveness of the various corrosion control measures specified for USMC application. These corrosion control measures consist primarily of the application and maintenance of various coatings and compounds which are intended to exclude the corrosive environment from a corrosion-susceptible base metal. Manuals are available for vehicle types and maintenance echelons, but the use of these manuals is erratic and service performance data on the recommended methods is limited. In order to identify research and development approaches which will provide cost-effective payback upon implementation, the effectiveness must be determined of presently specified corrosion control methods in reducing corrosion problems in service.

APPROACH

Four interconnected subtasks have been identified by NSWC to improve corrosion performance of Marine Corps vehicles:

The first effort is to conduct inspections of Marine Corps vehicles by corrosion engineers to identify those components, materials and design aspects common to most vehicles which result in high corrosion susceptibility and resulting maintenance costs, which can not be substantially improved by present corrosion control efforts. A high payback R&D effort should result when the most expensive problems are then addressed for solution.

An evaluation of improved maintenance practices based on state-of-the-art corrosion control in both private industry and all military services will lead to immediate improvements through technology transfer, while identifying promising technologies requiring R&D evaluation for USMC applications. A literature review is in progress.

Design analyses will be conducted of present and proposed vehicle and equipment designs to identify life-enhancing backfits for existing assets and to permit inclusion of corrosion control criteria in purchase specifications which will lead to extended service life.

Research and Development Test and Evaluation (RDT&E) will be conducted for improved materials, designs, repairs and backfits to identify comparatively outstanding candidates for fleet evaluation and ultimate integration.

In order to develop cost-effective corrosion countermeasures for USMC vehicles, the current corrosion problems require definition. The first part of this task is to identify the corrosion problem areas of operating vehicles and review current corrosion control procedures and their overall effectiveness. In order to accomplish this, corrosion inspections of vehicles and equipment are being performed at major USMC bases and maintenance facilities. At these sites, inspections and discussions are conducted with personnel responsible for corrosion control and maintenance of vehicles.

During early FY94, personnel from NSWC visited Camp Lejeune, Camp Pendelton, and Twenty-nine Palms Marine Corps Bases. These sites were selected due to the variety and amount of vehicles, and the differing environments. Most of the inspected vehicles were in operational condition and had been in typical environments around their respective bases since their last major refurbishment or overhaul. Future inspections are planned for vehicles at Depot Level Maintenance Activities (5th echelon) and vehicles returning from deployment aboard ship. Vehicle types inspected included Amphibious Assault Vehicles (AAV), High Mobility Multipurpose Wheeled Vehicles (HMMWV), Light Armored Vehicles (LAV), Logistic Vehicle Systems (LVS), M1A1 Main Battle Tanks, 5-ton trucks, and various heavy landing support equipment. This report

summarizes the inspections, reviews current maintenance practices, and provides initial identification of general corrosion problems affecting USMC vehicles. These initial inspections will provide a baseline for corrosion control recommendations for present vehicles and will direct the research and development of future vehicles.

CORROSIVITY OF LOCAL ENVIRONMENTS

In general, the severity of marine environments is directly related to salt water exposure time. For equal time periods, severity of exposure is generally highest for direct immersion, followed by splash/spray, and then salt air exposure as a function of distance from the ocean ref 5. However, any exposure that results in collection of salt (chlorides) in metal crevices will continue to cause corrosion in any humid environment until the salt is flushed out.

In the atmosphere, corrosivity increases as the moisture level and the chloride concentration increases. The two primary sources of chlorides in the atmosphere are sea salt near coastal locations and road salt which is used primarily for deicing roads. For Marine Corps vehicles, the effect of road salt is expected to be insignificant when compared to the effect of sea salt in the marine atmosphere.

Transportation and Operation

Marine Corps vehicles are subject to salt water immersion during coastal and amphibious operations, and to salt spray during transportation aboard LCAC's and assault ships. These factors contribute to a severe service environment in which corrosion is a major maintenance consideration. Particular consideration should be given to proper application of corrosion control materials and procedures before and during ship transport.

Base Location

The corrosion surveys revealed the operating location of the vehicles to be a major factor in determining the amount of corrosion observed. In general, the vehicles inspected at 29 Palms had the least corrosion. Those inspected at Camp Lejeune had the most corrosion. Those inspected at Camp Pendleton had slightly less corrosion than those seen at Lejeune but markedly more than those seen at 29 Palms.

The primary influences at both Camp Lejeune and Camp Pendleton would be exposure to the marine atmosphere and the use of vehicles for amphibious operations. The vehicles at 29 Palms are not subject to either of these influences and have very little corrosion. The

factors differentiating between Pendleton and Lejeune are less obvious. They consist of total precipitation and the number of days with rainfall as well as the concentration of industrial pollutants.

No surveys were conducted of III MEF vehicles on Okinawa. As Okinawa is an island, the chloride concentration in the atmosphere is likely to be higher than at any of the other locations. Therefore, the corrosion of vehicles based on Okinawa is expected to be greater than at the other sites.

GENERAL VEHICLE CORROSION PROBLEM AREAS

Coatings

In general, the use of Chemical Agent Resistant Coating (CARC) was considered a problem by most of the maintenance activities. Although CARC appeared to have adequate performance if applied properly, the environmentally strict application allowances severely limited its overall effectiveness. Only one quart per day per area is permitted according to volatile organic compound (VOC) regulations. This greatly restricts reapplication of a poor coating and allows very little touch-up.

Because of the problems associated with CARC, Zn-Silicate IC-531 coating has been proposed as an alternate coating for USMC vehicles. IC-531 has a zero VOC rating so it can be applied without the restrictions found with CARC. It has already been applied on a few vehicles at Camp Pendelton for in-service testing. However, poor controls were exercised during application, coatings experts were not involved, and the resulting applications poorly documented. In addition to a better controlled evaluation of the IC-531 system, more comprehensive research is needed on possible CARC alternatives.

Certain areas on the vehicles suffer severe environments where coatings often failed and a more effective coating was needed. These included high temperature areas on the engine and exhaust systems. 1st Recon. at Camp Pendelton was field testing a high heat aluminum paint overcoated with Amlguard on certain high temperature connectors on the LAV engine. A coating was also needed on the underside of motor transport vehicles. Heavy amounts of corrosion were found in areas where coatings had failed or where coatings had not been applied.

Electrical Connectors

Electrical connectors were found to be consistently corroded on the various inspected vehicles. The design and geometry of these aluminum connectors leave these components susceptible to corrosion. Crevice areas were found to be the primary problem, especially under locking

collars and rubber seals. These crevices allow moisture and salt deposits to build-up which then caused accelerated attack.

Certain corrosion control methods were being attempted, but the effectiveness of these methods was unclear. Primarily, Amlguard or similar coatings were used in an attempt to exclude the connectors from the environment. Sometimes the connectors were wrapped with electrical tape. It is not known whether the observed failures were from improper application of these methods or whether the methods themselves were inadequate to prevent corrosion. More failures were observed at Camp Lejeune. It could be that the Amlguard-type coatings may work well for Camp Pendleton's drier environment but can not adequately withstand the harsher environment of Camp Lejeune. However, it is also possible that the application procedures are more easily followed at Camp Pendleton (drier surfaces during application), and better training is required at Lejeune. Field testing is needed where application of the coatings are documented and known to be correct, and performance of the coatings subsequently tracked.

If the current corrosion control methods prove to be ineffective, then other methods may require research. While the backfit of aluminum electrical connectors with non-metallic bodies may provide adequate performance, water exclusion methods from the present aluminum connectors involving coatings and/or plastic tapes or wraps could be comparatively evaluated.

One method approved for use with topside electrical connectors on Navy ships is cold-shrink tubing. Cold-shrink tubing is similar to heat-shrink tubing, but requires no heat guns or other application appliances. Application of cold-shrink tubing should work better than properly applied electrical tape and is easier to apply. The Navy has conducted an extensive evaluation of various methods (tapes, heat and cold shrink tubing) to reduce corrosion of electrical connectors. The comprehensive Navy report of those evaluations recommended cold/heat shrink tubing as interim corrosion control methods, until more corrosion resistant connectors could be fielded.

<u>Seawater Leakage Through Turrets</u>

On the amphibious and light armor vehicles, leakage of seawater through turret areas (particularly during LCAC transport) was found to be a major problem. The turrets were found to be ineffectively sealed and allowed seawater to leak through during any waterborne operation or transport on ship where seawater splashed on the vehicles. This typically caused corrosion of components below the turret area including

connectors, fittings, fasteners, etc. These components are usually inadequately protected since they are inside the vehicles and not designed for direct exposure to seawater.

Although some maintenance activities were concentrating on applying protective coatings to the susceptible components beneath the turrets, an effective sealing method for the turrets would be a simpler and less labor intensive fix. Development of a nonmetallic skirt or boot for installation around the turrets is one possibility.

Vision Blocks

The steel frame around the vision blocks in the turrets of amphibious and light armor vehicles were often corroded. This becomes a problem when the steel corrosion products leak onto the glass surface and subsequently impair vision. The current sealant appears to be ineffective in keeping moisture from coming into contact with the steel frame. 1st Recon. Bn. at Camp Pendelton reported this to be a poor sealant application at the depot level so they remove and reseal vision blocks on newly acquired vehicles. The performance of properly applied sealant should be tracked to assess its effectiveness and whether a new sealant or method is needed.

Water Collection Areas and Crevices

Water collection areas are areas that allow build-up of pockets of water, or moisture and deposits which increases the rate of corrosion due to the prolonged exposure to a corroding environment. These areas were found in many instances on the inspected vehicles including the frame of the HMMWV, hatch areas of the LAV, spot welds on trucks and trailer beds, and battery boxes for trucks. Proper corrosion control design of a vehicle should minimize any areas where moisture could be trapped.

Certain actions could be taken to limit the problems associated with water build-up. Drain holes can be drilled which allow water to leak out of trapped areas. This is especially needed for the frame of the HMMWV where holes in the side of the frame allow water in, but the bottom of the frame does not contains any holes to allow the water to drain out. Some newly acquired frames had drain holes but this was not always the case. The various maintenance activities could drill drain holes on any HMMWV frame without them. Battery boxes could also use better drain holes. Another option for battery boxes would be to also include a plastic insert which houses the batteries and allows the acid/water mixture to drain without coming into contact with the steel box. A new development, which should be tracked for general performance, is the introduction of plastic

battery boxes on m800 series trucks. The effort could easily be expanded to include their evaluation on other vehicles, and perhaps to include tool boxes as well.

To eliminate crevices from spot-welding, a continuous weld should be considered on future manufactured vehicles. On existing vehicles, an evaluation could be made of thin water displacing compounds which may fill crevices by capillary action, and provide some measure of corrosion resistance.

Fasteners

Failure of the cadmium electroplating was often observed on the Cd-plated fasteners and many of the fasteners had heavy rusting of the steel substrate. A change to a corrosion resistant coating for low strength bolts might provide better performance. An example is Sermetel, an aluminum-rich ceramic coating used with success on fasteners on Navy ships. Marine atmosphere and immersion exposure tests (environments similar to those experienced by USMC vehicles) showed improved performance over cadmium electroplate, ref 6.

Hydraulic Pistons

On heavy landing support equipment, hydraulic piston rods often had pitting of the chrome plating. This reportedly causes wear and eventual failure of the piston seals. Alternative coating materials should be examined. While other electroplating materials, such as nickel, can be evaluated, two promising methods include superpolished high-velocity oxy-fueled plasma sprayed titanium (or other metals) and plasma sprayed materials which contain ceramics, such as Ceramax 1000tm. The Ceramax 1000 is used on underwater hydraulic cylinders which open and close canal locks (gates).

Headlight Frames

Corrosion of steel headlight frames on HMMWVs is a problem which should be easily corrected by using an alternative material. An aluminum alloy should be available which has the mechanical properties required for the steel frames but has improved corrosion performance.

MAINTENANCE PRACTICES AND GUIDANCE

The maintenance and corrosion control practices varied considerably between the maintenance activities. Although standardized technical manuals and guidances are available, activities follow their own guidelines for corrosion control. These guidelines typically incorporate

some of the methods in the standard guidances but often include familiar or available materials and practices. Both 2nd and 3rd Bn. AAV maintenance have developed their own manuals for corrosion control.

The non-standard use of maintenance practices makes assessing the performance of the recommended methods of corrosion control in the technical manuals very difficult. Without standard practices uniformly implemented, no assumptions can be made with respect to the proper use or application of a corrosion control method. When a corrosion problem area on a vehicle was observed, it was often not determinable whether the recommended method had been used or applied properly, or applied properly but still provided ineffective performance. Before further research and development is conducted to solve vehicle corrosion problems, the service performance of the presently recommended corrosion control methods should be quantified. If the presently recommended methods are effective but are not being followed, research and development of new methods will not provide any improved performance. The Marine Corps Systems Command is in the process of developing a new corrosion control order which should assure the proper use of the technical manuals and implemenation of the recommended corrosion control methods. Tracking of these methods in service is needed to evaluate their effectiveness and direct R&D efforts. At this point, the fastest determination of effectiveness may be to do a side-by-side demonstration of the recommended corrosion control methods on several vehicles, comparing their performance to two untreated controls.

It is occasionally evident that no corrosion control is practiced at all for certain maintenance evolutions. During corrosion surveys at Twentynine Palms, a rebuilt engine for an AAV was observed to be in poor condition. Corrosion of previously identified susceptible components had neither been repaired nor treated with corrosion preventive compounds.

The lack of authoritative guidance for corrosion control has permitted maintenance activities to implement new corrosion control methods where existing methods were presumed ineffective. In particular, 1st Recon. at Camp Pendelton has attempted to develop an effective corrosion control program for the LAV. Unofficial field tests are being conducted on alternate methods for problem areas including a high temperature Al paint for fittings on the engine. To provide benefit to the entire corps, the tests should be repeated under controlled and documented conditions.

A recommendation was proposed by 1st Recon. to incorporate any corrosion control procedures into the vehicle assembly guidance. This

would require only the use of one manual during assembly and simplify the application of corrosion control. 1st Recon. had already handwritten their corrosion control methods in the margins of their assembly manual.

RESEARCH AND DEVELOPMENT, TEST AND EVALUATION

Coatings

While new low-VOC CARC coatings are presently under evaluation, corrosion tests will be required to determine which primer coatings as well as CARC coatings provide the best corrosion resistance to both steel and aluminum substrates. Included in the evaluation should be the zinc silicate coatings which have already been applied to several Marine Corps vehicles at Camp Pendleton. While fluidized bed epoxies should be considered for evaluation on vision ports, alternate vision port body materials, like aluminum or stainless steel should be considered.

Compounds

Most of the presently approved thin coatings for field use, except for the AMLGARD spray coatings, provide poor protection. Substitutes which provide high capillarity, water displacement and film "toughness" will be sought for comparative evaluation.

Materials

Both new materials for future marine corps vehicles and materials substitutions for existing components on present vehicles will be evaluated for life cycle improvements in performance. Aluminum alloys 2519 and 5083 presently being considered as hull materials for the new amphibious assault vehicle, and austenitic stainless steel fasteners (as well as coated steel fasteners) which are being considered for AAV applications can be comparatively tested in the marine environment. Based on the poor fleet performance of aluminum electrical connectors, a significant effort is justified in the development of alternate materials (stainless steel or composite material) for electrical connectors.

An aluminum headlamp retention bracket should be fabricated and placed in comparative marine exposure tests with the standard steel ones presently used on HUMVEEs and trucks.

Exhaust system components are repaired and replaced often, and would significantly benefit from an aggressive evaluation effort of advanced materials for backfit exhaust systems, as well as high temperature coatings. Both ceramic and metallic based plasma sprayed materials may provide improved service life for hydraulic cylinder rods, but require some development for specific Marine Corps applications and

eventual marine corrosion testing.

Plastics and composites may provide significant relief from corrosion attack on some non-structural components, such as battery and tool boxes. An effort to utilize non metallic materials (skirts, boots, tarps) to exclude the environment from vehicles and components may also be fruitful.

Environment Control

One means to reduce atmospheric corrosion is to isolate materials from the aggressive environment. Several approaches are available to exclude the environment from vehicles.

Since LCAC-transport is considered to be among the harshest operating environments to which Marine Corps vehicles are exposed, a means to reduce the amount of salt spray to which vehicles are exposed while in transit may serve to alleviate corrosion damage. The use of covers for LCAC's would shield vehicles from the salt spray and may reduce corrosion by isolating materials from an aggressive environment.

Corrosion of the internal components of some amphibious vehicles is worsened by seawater ingress during waterborne operations. The turrets generally provide the easiest path for seawater intrusion into the vehicle, and may benefit from the use of a skirt designed to make the turret more watertight.

Another technique for environmental control under investigation by the Marine Corps is the use of active dehumidification. It has been found that maintaining a relative humidity of 30% - 40% greatly diminishes the effects of atmospheric corrosion.

Active dehumidification has been used by Israeli Defense Forces, the Swedish and Danish Air Forces, and Swedish and German Armies. It has been applied to aircraft by the U.S. Army, Navy and Air Force.

Dehumidification is currently being pursued by the Marine Corps (II MEF), both for the preservation of materials in long term storage, and for active-status materials. Active dehumidification is currently used by the U.S. Navy for the preservation of some inactive ships. It may be feasible for Marine Corps vehicles intended for long-term storage to be loaded aboard inactive assault ships already equipped for the dehumidification of internal spaces. The feasibility and cost-effectiveness of storing Marine Corps vehicles aboard inactive assault ships should be investigated.

Design Analysis

The feasibility of integrating corrosion engineering into new vehicle and component design will be demonstrated. Particular attention will be

paid to when during the design process that corrosion engineering should be applied, as well as the initial development of standard phraseology for integration into design standards and specifications.

Using the AAAV, and other new Marine Corps vehicle designs (perhaps the 8 ton truck), performance and materials compatibility issues resulting from the new designs which may require corrosion tests to resolve will be identified.

Field Tests

While comparative corrosion testing of standard coupons is often necessary to resolve a range of candidates for service evaluation, there is also the opportunity to immediately evaluate some materials in service to demonstrate improved performance or the need to develop alternate materials and methods. As the Marine Corps has not implemented many of their own standard corrosion control practices fleetwide, it would be prudent to field test some of their specified materials for corrosion control alongside a few alternate or optional replacement materials and methods. A demonstration could be conducted on two vehicle types (eg, AAVs and HUMVEES) of say, five vehicles each, while holding another five each as controls with no special corrosion countermeasures. Properly set up and controlled, the field tests would provide numerical justification for fleetwide implementation of corrosion control and an excellent training opportunity in corrosion control application. Field tests should probably be conducted simultaneously at Camps Lejeune and Pendleton, and at Okinawa.

SUMMARY AND RECOMMENDATIONS

Inspections of United States Marine Corps amphibious vehicles, tanks, transport vehicles, heavy landing support equipment and artillery are in progress to identify common corrosion problems which may require research and development to improve. Issues related to establishment of a consistent and coherent corrosion control program for USMC vehicles have been discussed in order to emphasize existing methods which may reduce corrosion without further development effort. The role of the severity of environmental exposure conditions has been identified to assist in the separation of materials issues from design or maintenance requirements. Backfit of new materials, coatings and compounds into existing equipment for improved corrosion performance as well as into new design may require comparative corrosion tests to validate life cycle cost payback.

REFERENCES

1. Metals Handbook on Corrosion, Ninth Ed., Vol. 13, ASM International, 1987.

2. Designing for Automotive Corrosion Prevention, Society of Automotive Engineers, P-78, 1978.

3. Atmospheric Corrosion of Metals, ASTM, STP 767, 1980.

4. Degradation of Metals in the Atmosphere, ASTM, STP 965, 1986.

5. Materials for Marine Systems and Structures, Treatise on Materials Science and Technology, Vol. 28, Academic Press, 1988.

6. Aylor, D.M. and P.A. Klein, "Corrosion Resistant Fasteners " Proceedings, 1985 Tri-Service Conference on Corrosion